From Corals to Canyons: The Great Barrier Reef Margin

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Development of a Pan-Arctic Database for River Chemistry

More than 10% of all continental runoff flows into the Arctic Ocean. This runoff is a dominant feature of the Arctic Ocean with respect to water column structure and circulation. Yet understanding of the chemical characteristics of runoff from the pan-Arctic watershed is surprisingly limited. The Pan-Arctic River Transport of Nutrients, Organic Matter, and Suspended Sediments (PARTNERS) project was initiated in 2002 to help remedy this deficit, and an extraordinary data set has emerged over the past few years as a result of the effort. This data set is publicly available through the Cooperative Arctic Data and Information Service (CADIS) of the Arctic Observing Network (AON). Details about data access are provided below.

Sampling programs were established on six rivers that account for more than half of all river discharge from the pan-Arctic watershed. Starting in western Siberia and moving eastward around the pan-Arctic domain, these rivers are the Ob', Yenisey, Lena, and Kolyma in Russia; the Yukon in Alaska; and the Mackenzie in Canada's Northwest Territories. In addition to the parameters highlighted in the PARTNERS acronym, the project also has measured many other parameters, including major ions, trace elements, and isotope ratios. While a variety of studies by PARTNERS scientists and others have focused on the chemistry of individual Arctic rivers, differences in methods and parameters measured have hampered river intercomparisons and understanding at the pan-Arctic scale. Furthermore, most previous studies of large Arctic rivers were conducted only during summer. Thus, implementation of standard protocols, including seasonally representative sampling, was a key consideration for the PARTNERS project.

The PARTNERS data set provides an essential baseline for detecting changes in the pan-Arctic watershed. The six rivers capture runoff from 10.34 million square kilometers, and thus changes in the chemistry of these rivers would indicate widespread changes in watershed processes such as permafrost dynamics, soil weathering, and microbial activity. While elucidation of specific mechanisms behind changes in river chemistry requires direct study of potential drivers, river chemistry provides an integrative signal that helps to constrain the possible mechanisms and thereby to develop informed hypotheses in support of more focused studies. For example, an increase in the age of river-borne dissolved organic carbon would point toward mobilization of ancient organic matter from thawing permafrost. High-quality baseline data also support better informed studies of how changes in river export may influence ocean ecosystems.

One of the primary goals of PARTNERS was to improve estimates of chemical parameters used to differentiate freshwater sources in the Arctic Ocean. These parameters include the isotopic composition of hydrogen and oxygen in water molecules as well as concentrations of barium and alkalinity that have been used to track river water in the Arctic Ocean. The resolution of freshwater sources has been relatively coarse due to uncertainty in estimates of tracer values for individual rivers. The PARTNERS data constrain these estimates by capturing seasonal dynamics and by facilitating the calculation of flow-weighted averages that better represent annualized inputs.

The full PARTNERS data set includes approximately 50 parameters. Twenty-four of these parameters are shown in Figure 1, where values for high flow in each river are expressed relative to the average for all rivers. This representation of the data highlights major differences in chemistry between the North American and Eurasian rivers. In particular, concentrations of uranium, barium, calcium, sulfate, and total alkalinity are much higher in the North

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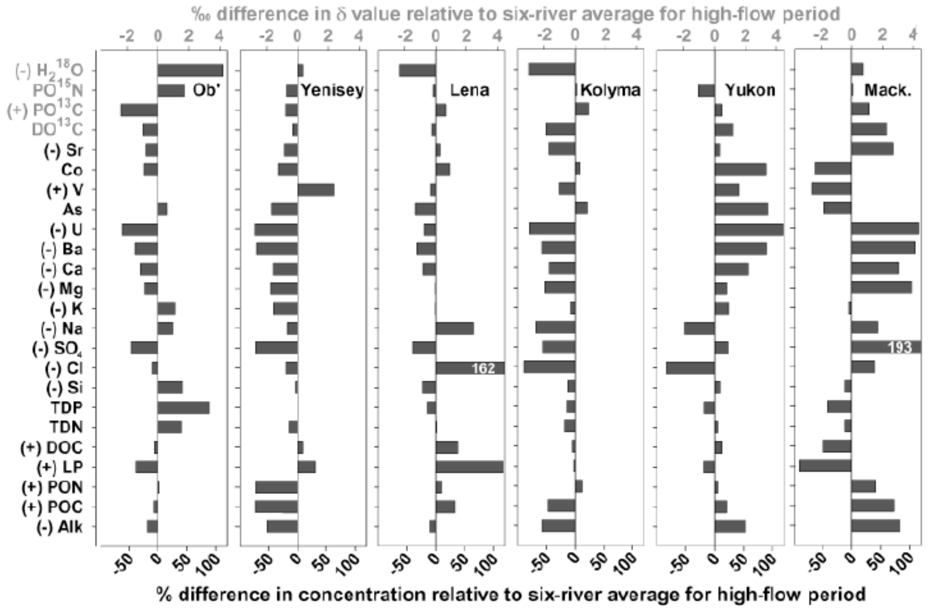

Fig. 1. Differences in chemistry among Pan-Arctic River Transport of Nutrients, Organic Matter, and Suspended Sediments (PARTNERS) rivers during high flow, late May through mid-June. Differences in isotope ratios are reported as δ values (‰). All other differences are percentages. Plus signs in front of parameter labels indicate increases from low to high flow at all rivers, and minus signs indicate decreases from low to high flow. $H_2{}^{18}O$ is the $\delta^{18}O$ of water, $PO^{15}N$ is the $\delta^{15}N$ of particulate organic nitrogen (PON), $PO^{13}C$ is the $\delta^{13}C$ of particulate organic carbon (POC), $DO^{13}C$ is the $\delta^{13}C$ of dissolved organic carbon (DOC), TDP is total dissolved phosphorus, TDN is total dissolved nitrogen, Alk is total alkalinity, and LP is lignin phenols. Values for Alk, LP, strontium (Sr), cobalt (Co), vanadium (V), arsenic (As), uranium (U), barium (Ba), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), sulfate ($SO_4{}^{-2}$), chloride (Cl^-), and silicon (Si) are from filtered (0.45-micron) samples.

From Corals to Canyons: The Great Barrier Reef Margin

The significance of submerged fossil coral reefs as important archives of abrupt global sea level rise and climate change has been confirmed by investigations in the Caribbean [*Fairbanks*, 1989] and the Indo-Pacific (see *Montaggioni* [2005] for a summary) and by recent Integrated Ocean Drilling Program (IODP) activities in Tahiti [*Camoin et al.*, 2007]. Similar submerged (40–130 meters) reef structures are preserved along the margin of the Great Barrier Reef (GBR), but they have not yet been systematically studied.

The submerged reefs have the potential to provide critical new information about the nature of past global sea level and climate variability and about the response of the GBR to these past and perhaps future environmental changes [*Beaman et al.*, 2008]. Equally important for GBR Marine Park managers is information about the role of the reefs as habitats and substrates for modern biological communities.

Here we summarize the highlights and broader implications of a September–October 2007 expedition on the R/V *Southern Surveyor* (Australian Marine National Facility, voyage SS07/2007) to investigate the shelf edge, upper slope, and submarine canyons along the GBR margin.

GBR Fossil Reefs

The multibeam, seismic, and autonomous underwater vehicle (AUV) imagery provides a comprehensive view of the morphology and spatial distribution of the fossil reefs and terraces along the shelf edge between 40 and 130 meters (Figure 1). The shelf edge is where the GBR has spent about 85% of its time over the past approximately 500,000 years as climate varied and sea level fluctuated back and forth across the shelf edge.

The new data reveal a diverse suite of surface and subsurface features that includes submarine terraces, complex relict fringing, barrier, patch reef, and lagoonal systems, along with paleoriver channels and relict dune systems. An example survey area near Cairns (Figure 1 inset) illustrates the high quality of the imagery and shows the relationship between a paleoriver channel system and the fossil reefs at the shelf edge. These features likely reflect a complex history of growth and erosion during periods of sea level change at lower sea levels relative to today. Preliminary observations of rock dredge samples suggest that the relict reef features may be capped by coral reef material deposited during the last deglaciation (20,000–10,000 years ago).

Deep Benthic Habitats

Little is known about the modern benthic communities associated with the shelf edge reefs, despite their widespread occurrence throughout the Great Barrier Reef World Heritage Area (GBR/WHA). The new AUV images show a diversity of benthic communities and substrate types that include red algae-encrusted fossil rock, thriving hard and soft coral, gorgonian (sea whip or fan) and sponge communities, and vast fields of *Halimeda* (green algae) covered substrate. Postcruise analyses of the AUV and multibeam data, together with the rock dredge and sediment samples, will provide quantitative information about the substrate and

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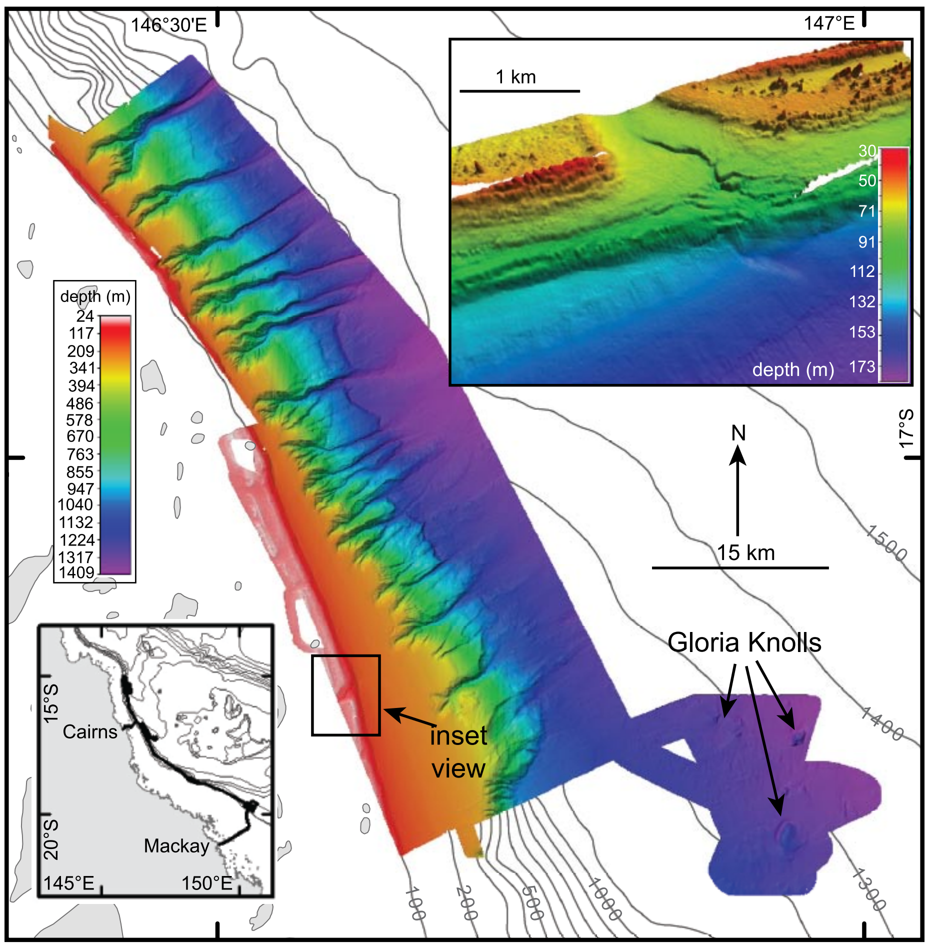

Fig. 1. Expedition ship track along the Great Barrier Reef (lower left) and a multibeam image of the survey area near Cairns showing the shelf edge, submarine canyons incising the slope, and debris fields at the base of the slope [after Webster et al., *2008]. The Gloria Knolls lie in the Queensland Trough at a depth of about 1100 meters. The inset shows an oblique view of the GBR shelf edge, fossil reefs, and paleochannel.*

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American rivers. There are also many striking differences in chemistry among rivers within each continental grouping. In contrast, seasonal patterns in chemistry are remarkably similar among rivers. This seasonality is tightly linked to hydrographic variations at all of the rivers, with individual parameters consistently showing positive or negative correlations with discharge (indicated in Figure 1 by plus or minus signs in front of parameter labels). Recent analyses of dissolved organic carbon export from rivers to the Arctic Ocean using PARTNERS data, including revised estimates of export quantity, age, and losses within the Arctic Ocean, are given by *Cooper et al.* [2005] and *Raymond et al.* [2007].

Sampling was conducted at Salekhard (Ob'), Dudinka (Yenisey), Zhigansk (Lena), Cherskii (Kolyma), Pilot Station (Yukon), and Tsiigehtchic (Mackenzie). These sites are located far down on each river and thus capture flow contributions from the vast majority of each river's watershed. PARTNERS participants completed 17 sampling trips on each river between summer 2003 and fall 2006. The trips were distributed in time to capture low flow during late winter (under ice), high flow during spring melt, and intermediate flow during summer/fall. Protocols were established using U.S. Geological Survey (USGS) guidelines, including the use of depth/flow integrating samplers. PARTNERS sampling on the Yukon was coupled with USGS work ongoing since 2001.

Funding for the PARTNERS project ended in fall 2007, but sampling will continue at the sites established during PARTNERS, at least through 2011, as a component of the developing AON. Within this network, the river sampling program is now identified as the Arctic Great Rivers Observatory (Arctic-GRO). The Arctic-GRO is being maintained by a subset of the PARTNERS participants, with Bruce Peterson as the lead scientist. The importance of the AON is underscored by observations of widespread changes in the Arctic during recent years [*Symon et al.*, 2005]. Many changes in the Arctic are coupled to the freshwater cycle and have feedbacks to global climate [*White et al.*, 2007].

Routine data for the Yukon River at Pilot Station are available at http://nwis.waterdata.usgs.gov/ak/nwis. All other PARTNERS data, including nonroutine data for the Yukon, are available on the CADIS Web site, under the Arctic-GRO heading (http://www.eol.ucar.edu/projects/aon-cadis/).

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References

Cooper, L., R. Benner, J. McClelland, B. Peterson, R. Holmes, P.A. Raymond, D. Hansell, J. M. Grebmeier, and L. A. Codispoti (2005), Linkage among runoff, dissolved organic carbon, and the stable oxygen isotope composition of seawater and other water mass indicators in the Arctic Ocean, *J. Geophys. Res., 110*, G02013, doi:10.1029/2005JG000031.

Raymond, P. A., J. W. McClelland, R. M. Holmes, A. V. Zhulidov, K. Mull, B. J. Peterson, R. G. Striegl, G. R. Aiken, and T. Y. Gurtovaya (2007), Flux and age of dissolved organic carbon exported to the Arctic Ocean: A carbon isotopic study of the five largest arctic rivers, *Global Biogeochem. Cycles, 21*, GB4011, doi:10.1029/2007GB002934.

Symon, C., L. Arris, and B. Heal (Eds.) (2005), Arctic climate impact assessment (ACIA), 1042 pp., Cambridge Univ. Press, New York.

White, D., et al. (2007), The arctic freshwater system: Changes and impacts, *J. Geophys. Res., 112*, G04S54, doi:10.1029/2006JG000353.

—JAMES W. MCCLELLAND, University of Texas at Austin, Port Aransas; E-mail: jimm@mail.utexas.edu; R. MAX HOLMES, Woods Hole Research Center, Falmouth, Mass.; BRUCE J. PETERSON, Marine Biological Laboratory, Woods Hole, Mass.; RAINER AMON, Texas A&M University, Galveston; TIM BRABETS, U.S. Geological Survey (USGS), Anchorage, Alaska; LEE COOPER, University of Maryland Center for Environmental Science, Solomons; JOHN GIBSON, University of Victoria, British Columbia, Canada; VIACHESLAV V. GORDEEV, Shirshov Institute of Oceanology, Moscow, Russia; CHRISTOPHER GUAY, Pacific Marine Sciences and Technology, Oakland, Calif.; DAVID MILBURN and ROBIN STAPLES, Water Resources Division, Department of Indian Affairs and Northern Development, Yellowknife, Northwest Territories, Canada; PETER A. RAYMOND, Yale University, New Haven, Conn.; IGOR SHIKLOMANOV, State Hydrological Institute, St. Petersburg, Russia; ROBERT STRIEGL, USGS, Denver, Colo.; ALEXANDER ZHULIDOV and TANYA GURTOVAYA, South Russian Regional Centre for Preparation and Implementation of International Projects, Ltd., Rostov-on-Don, Russia; and SERGEY ZIMOV, Northeast Science Station, Cherskii, Russia

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modern benthos composing these reef systems. Taxonomic, ecologic, and molecular biology studies will investigate whether these biota are distinct from their shallow reef counterparts and whether the living biota on the shelf edge reefs have the potential to act as refugia, reseeding the shallow reef after disturbance events.

Submarine Canyon Systems

The multibeam and seismic data also reveal a spectacular network of submarine canyons, slump scars, and landslide deposits on the continental slope and upper basin. These data provide unique insight into the fundamental processes that have shaped the evolution of the GBR margin. Figure 1 shows numerous V-shaped canyons incising the slope, suggesting that active erosion is taking place. Tension cracks and smaller feeder canyons around the heads of the canyons are observed at depths of approximately 250 meters. The canyons often terminate in slide scarps and debris fields where progressive upslope erosion has reduced the stability of the parent margin sediments. These data will also provide important baseline seabed physical data as proxies for benthic habitats and biodiversity in the deep GBR/WHA.

Gloria Knolls

Existing Geological Long-Range Inclined Asdic (GLORIA) side-scan sonar data [*Hughes Clarke*, 1994] along the GBR margin showed numerous high-backscatter features in the Queensland Trough. We investigated the features in detail and discovered a cluster of eight knolls—the largest of which is more than 2 kilometers long and more than 100 meters high—in depths of approximately 1100 meters (Figure 1). Seismic profiles across the knolls revealed they are discrete, seismically opaque blocks capped by approximately 15 meters of soft sediments. A rock dredge across the largest knoll recovered evidence of a cold-water coral community comprising abundant live and dead hard colonial corals, barnacle plates, gastropods, and manganese-covered concretions within a muddy matrix of carbonate sediments. These findings suggest the blocks may have broken off the GBR margin as catastrophic landslides, sliding down the lower slope and coming to rest in the basin where they now form a habitat for the deep, cold-water coral communities. We named these fascinating features the Gloria Knolls, and they represent the first documented case of such a habitat adjacent to the GBR/WHA.

Conclusions

These new observations reveal a stunning and diverse picture of the deep margin of the GBR. Postcruise analyses of the marine geophysical, geological, and biological data are now focusing on accurate high-precision dating, paleoclimate proxy reconstructions, sedimentary facies, community dynamics, and geomorphic studies. These data will provide new information about the nature of sea level and climate change variability and constrain the natural rate and range of coral reef community change to these past environmental stresses. Finally, these data also satisfy site survey requirements for an IODP expedition to drill the GBR fossil reefs scheduled for September–December 2009.

Acknowledgments

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References

Beaman, R. J., et al. (2008), New evidence for drowned shelf edge reefs in the Great Barrier Reef, Australia, *Mar. Geol., 247*, 17–34.

Camoin, G. F., et al. (2007), *Proceedings of the Integrated Ocean Drilling Program: Expedition Reports—Tahiti Sea Level*, vol. 310, doi:10.2204/iodp.proc.2310.2101.2007, Integrated Ocean Drill. Program Manage. Int., Washington, D. C.

Fairbanks, R. G. (1989), A 17,000-year glacio-eustatic sea-level record: Influence of glacial melting rates on the Younger Dryas event and deep ocean circulation, *Nature, 342*, 637–642.

Hughes Clarke, J. (1994), Toward remote seafloor classification using the angular response of accoustic backscattering: A case study from multiple overlapping GLORIA data, *IEEE J. Oceanic Eng., 19*, 112–127.

Montaggioni, L. F. (2005), History of Indo-Pacific coral reef systems since the last glaciation: Development patterns and controlling factors, *Earth Sci. Rev., 71*(1-2), 1–75.

Webster, J. M., et al. (2008), Evolution of drowned shelf edge reefs in the GBR; implications for understanding abrupt climate change, coral reef response and modern deep water benthic habitats—RV Southern Survey, voyage summary, 18 pp., Mar. Natl. Facil., Hobart, Tasmania, Australia. (Available at http://www.marine.csiro.au/nationalfacility/voyagedocs/2007/summarySS07-2007.pdf)

—JODY M. WEBSTER, ROBIN J. BEAMAN, and THOMAS BRIDGE, School of Earth and Environmental Sciences, James Cook University, Townsville, Queensland, Australia; E-mail: jody.webster@jcu.edu.au; PETER J. DAVIES, MARIA BYRNE, STEFAN WILLIAMS, PHIL MANNING, OSCAR PIZARRO, KATE THORNBOROUGH, and ERIKA WOOLSEY, University of Sydney, New South Wales, Australia; ALEX THOMAS, Oxford University; and SANDY TUDHOPE, University of Edinburgh, Edinburgh, UK